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Application of Oxy-Fuel CO_2 Capture for In-Situ Bitumen Extraction from Canada's Oil Sands

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Abstract

The CO_2 Capture Project, along with Praxair, Devon Canada, Cenovus Energy and Statoil ASA are executing a project to demonstrate oxy-fuel combustion as a practical, economic and commercially ready technology for CO_2 capture from once through steam generators (OTSGs) used in the in-situ production of bitumen.

While in-situ extraction methods are less invasive than mining and have less local environmental impacts, the current technology for in-situ extraction - steam assisted gravity drainage (SAGD) - is more energy intensive, and will result in greater GHG emissions per barrel of oil produced as compared to conventional mining and hot water extraction processes. SAGD requires large quantities of steam for injection, which is produced by multiple large once-through steam generators (OTSGs) that each produce up to 250 kt/yr of CO_2, depending on their size.

Given this expected growth in the total GHG emissions from OTSG units in the oil sands, the Participants have initiated a project to prove and validate process designs for oxy-fuel combustion on OTSG boilers. The three phase project will assess the feasibility, cost and schedule required to utilize oxy-fuel combustion at a typical commercial site. The study will include a short term boiler test and a longer term pilot evaluation. The goal of the project is to develop a reliable, lower cost solution for capturing CO_2 from OTSG boilers that is deployable at commercial scale.

The primary technology provider for this project is Praxair. Other members include Devon Canada, Cenovus Energy, Statoil ASA and the CO_2 Capture Project. The CO_2 Capture Project is a joint venture research consortium that includes BP, Chevron, ConocoPhillips, ENI, Petrobras, Shell and Suncor.

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1. Introduction

With as much as 173 billion barrels of economically recoverable oil, Canada's oil sands are second only to Saudi Arabia in terms of size, and are unparalleled in growth potential. Current production from the Canadian oil sands is just over 1 million barrels per day (MMBPD); the Canadian Association of Petroleum Producers estimates that this could grow to almost 4 MMBPD by 2020. Most of this growth is expected to come from in-situ extraction methods, as over 80% of Canada's oil sands are too deep to be mined with existing technologies[i].

While in-situ extraction methods are less invasive than mining and have less local environmental impacts, the current technology for in-situ extraction - steam assisted gravity drainage (SAGD) - is more energy intensive, and will result in greater GHG emissions per barrel of oil produced as compared to mining and extraction processes[ii]. SAGD requires large quantities of steam for injection, which is produced by multiple large OTSGs, each producing up to 250 KT/yr of CO_2.

Given this expected growth in the total GHG emissions from OTSG units in the oil sands, the Participants have initiated a project to prove and validate process designs, costs and operability of an innovative technology to capture carbon dioxide from in-situ operations. The technology, known as oxy-fuel combustion uses oxygen produced by an air separation unit instead of air for combustion. By eliminating nitrogen, the flue gas has a very high concentration of CO_2, and requires minimal clean-up prior to compression and transport to long-term geologic storage.

Oxy-fuel combustion offers several advantages over competing CO_2 capture technologies for gaseous fuels boilers, including:

- Lower levelized capture cost
- Lower total energy and O&M costs
- Significant reductions in emissions of criteria air contaminants, including oxides of nitrogen, sulphur dioxide and carbon monoxide
- Recovery of water from the flue gas, reducing or eliminating boiler make-up water
- No requirements for amine solvents, which may pose environmental and challenges

The three-phase project will assess the feasibility, cost and schedule required to use oxy-fuel combustion at a typical commercial site. It is planned to include a short term boiler test and a longer term pilot evaluation. The goal of the project is to develop a reliable, lower cost solution for capturing carbon dioxide from OTSG boilers that is deployable at commercial scale.

2. Project Participants

The Project Participants have assembled a strong team of collaborators to ensure the successful execution of the project. The Project Manager is Suncor Energy, and the primary technology provider for this project is Praxair. Other members include Devon Canada, Cenovus Energy, Statoil ASA and the CO_2 Capture Project (CCP). CCP is a partnership of the world's leading energy companies, working with academic institutions and government organizations to research and develop technologies to help make CO_2 capture and geological storage (CCS) a practical reality for reducing global CO_2 emissions and tackling climate change. Current members of CCP are BP, Chevron, ConocoPhillips, ENI, Petrobras, Shell and Suncor.

3. Importance of CCS solution for Oil Sands

The current state of the art extraction method is steam-assisted gravity drainage (SAGD) with steam generated through OTSGs. These units consume large quantities of fossil fuels for operation, and emit correspondingly large amounts of CO_2 Current CO_2 capture technologies, based on post-combustion capture with amines are impractical due to the dilute nature of the flue gas, as they are prohibitively expensive, and require large amounts of energy in the form of steam and solvents to operate.

From the Participants perspective, the ability to reduce GHG emissions from these in-situ operations in a cost-effective manner is a matter of strategic importance. The implementation potential of oxy-fuel OTSG boilers for CO_2 capture is significant; currently there are 15 in-situ operators in the province, with a design capacity of almost 700,000 barrels per day. In addition, there are significant growth plans for the sector; it is expected that in-situ resource development will be the preferred method for bitumen extraction for the majority of new projects. Based on the current installed OTSG capacity and the anticipated growth, it is likely that there would be well over 100 OTSG boilers in the province that could be retrofitted for CO_2 capture with oxy-fuel technology. This would represent on the order of 20-30 MT/yr of avoided CO_2 emissions if oxy-fuel combustion technology was implemented on these units.

4. Comparison of Capture Technologies for OTSG Capture

Currently, the most commercially ready technology for capturing CO_2 from OTSGs is post-combustion capture with amine solvents. In this type of capture system the flue gas is cooled and then passed through an adsorption tower, where the CO_2 is selectively absorbed by the amine solvent. The flue gas, largely free of CO_2 is then released to the atmosphere, and the solvent is regenerated in a stripping tower, where CO_2 is desorbed and captured. This technology is both capital and energy intensive. In addition, the health and environmental performance of the amine process is uncertain; for example, nitrosamines may form by means of reactions with oxides of nitrogen, and these compounds may have long-term environmental impacts[iii iv].

Oxy-fuel combustion technology uses high purity oxygen, produced from an air separation plant instead of air as the fuel oxidant. By substituting oxygen for air the flue gas volume is dramatically reduced, and it consists largely of CO_2 and water vapour. With this pre-concentration the CO_2 can be cost effectively purified via cryogenic methods, and once purified, compressed and made available for sequestration.

Oxy-fuel combustion has some unique advantages over post-combustion capture technologies for this application, and includes:

- Although the air separation and CO_2 compression and purification processes require energy in the form of electricity, they consume minimal amounts of steam. Oxy-fuel combustion

process will have excellent environmental performance with very low emissions of SO_X and NO_X. Since no solvent is needed there will be no other potentially harmful emissions from the process
- An oxy-fuel fired boiler will typically use 2-6% less fuel than a traditional air fired boiler without CO_2 capture, because of the high temperatures of the recycled flue gas
- Very high (>98%) CO_2 capture rates are feasible, because the entire flue gas is captured, and achieving very high recovery rates does not incur a significant energy penalty.
- Oxy-fuel CO_2 capture will result in the recovery of the majority of the water vapour in the flue gas, resulting in large quantities of water being available for boiler feedwater makeup and other uses. It is notable that sourcing water for SAGD projects can be a major challenge

In addition the oxy-fuel technology will have the following benefits:

- Oxy-fuel fired boiler operation is very similar to air-fired operation. This aspect will make adoption of the technology by oil producers easier.
- Oxy-fuel technology's ability to operate as either an air-fired or oxy-fired boiler provides the operator flexibility in design when regulations may still be in flux and when oil recovery operation is continued when the air separation unit is not available.
- Oxy-fuel combustion technology is fully applicable for retrofitting existing plants. The footprint near the boilers is relatively small.

The electric power generating method can be very important when considering oxy-fuel combustion as electric power is the main energy consumer of the oxy-fuel process. With in-situ operations the electricity is most likely generated from natural gas plants, either natural gas combined cycle or cogeneration, which have significantly lower emissions than coal-fired generation. Including the emissions from power production it is expected that the technology will result in avoided CO_2 emissions from OTSGs in greater than 75%.

5. Description of Oxy-Fuel OTSG Technology

The main components of the system include an air separation unit (ASU) to provide the combustion oxygen, an OTSG modified with flue gas recirculation to allow for safe operation with the ability to revert to air, and a CO_2 Processing Unit (CPU) with compression.

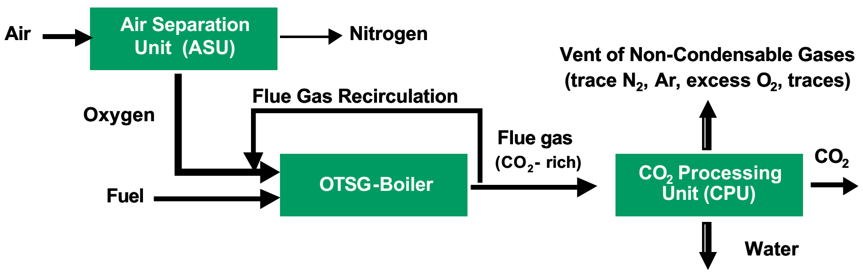

Figure 1: Major Components for CO_2 Capture from OTSGs with Oxy-fuel Combustion

The individual components that are used for oxy-fuel combustion are proven technology. On the front-end the major process addition is the ASU. Cryogenic air separation units have been in commercial operation for over a century and is a mature, robust technology, with on-stream factors often exceeding 98%. The ASU will use an advanced process optimized with the entire system to provide oxygen with the best purity and pressure for low energy consumption and overall lowest CO_2 capture costs. A single ASU can be used to supply oxygen to several individual boilers on the SAGD site.

The OTSG will require minor modifications to allow flue gas recirculation so that operation is maintained similar to the air design performance. These boilers consist of a radiant section serves to evaporate the feedwater to steam and a convective section (economizer) where the feedwater is preheated. The two sections are designed to be properly balanced with air combustion. When oxygen is used for combustion, the nitrogen of the air is eliminated, resulting in a significantly lower flue gas flow, which lowers the heat transfer in the economizer and increases the heat transferred in the furnace. In addition, the use of oxygen results in very hot flames and high radiant heat transfer if the oxygen is not diluted with flue gas.

High radiant heat fluxes are a concern for boiler operation due to the potential for boiler tube dry out and subsequent tube damage. Therefore flue gas from the boiler outlet will be recirculated to substitute mainly CO_2 and water vapour for the nitrogen that would have been present with air operation. In this manner, the correct convective / radiative heat transfer balance can be maintained, and safe, efficient boiler operation assured.

The oxy-fuel combustion system will consist of control systems for fuel gas and oxygen and a burner to combust the gas with oxygen and re-circulated flue gas. It is desirable to provide combustion capability for both oxygen and air. The boilers would be started up using air and switched to oxy-fuel operation when the ASU is on line. Then the CO_2 Processing Unit (CPU) is put in service to produce CO_2 for sequestration. In case the ASU or CPU units are unavailable, the boilers can be operated using air in a conventional matter to maintain site steam production.

At the inlet of the CPU the raw flue gas is cooled to nearly ambient temperature before entering a multi-stage raw gas compressor. As the flue gas is cooled and compressed, moisture will drop out as condensate stream and a dryer bed is used to remove any residual moisture to a level suitable for a cryogenic separation. The cleaned and compressed CO_2–rich flue gas is sent to a cold box which uses a partial condensation process. As the compressed, dry CO_2 stream is cooled to a temperature at which a majority of the CO_2 condenses, most of the non-condensibles in the stream including oxygen, nitrogen, argon, etc., remain in the gas phase, and are removed using a separator. A portion of the CO_2 stream is then expanded to provide refrigeration in the cold box. Both the CO_2 and the waste inert stream are warmed against the incoming feed stream. The purified CO_2 stream is compressed to approximately 10 MPa for pipeline transport to a suitable location for long-term geologic sequestration. If high CO_2 recovery (>98%) is desired a vacuum pressure swing adsorption (VPSA) can be added to further process the vent stream.

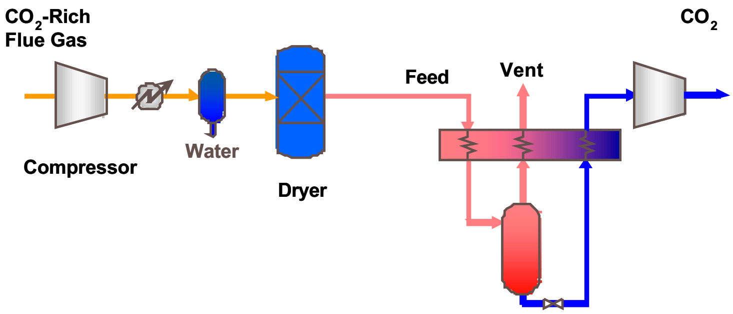

Figure 2: Schematic of the flue gas recovery and purification system.

The demonstration of oxy-fuel technology is planned at pilot scale on an existing 50 MMBTU/hr OTSG boiler. In this Phase II of the program the OTSG boiler will be modified for oxy-fuel operations and operated for up to one month to demonstrate the technical feasibility of oxy-fuel as a means of producing a more pure CO_2 exhaust stream from OTSG operations.

A major focus is the integration of the oxy-fuel combustion system into the boiler and the design of the control system. An external recirculation loop will be added to the boiler to be able to manage boiler heat transfer requirements. Three different oxy-fuel combustion concepts will be demonstrated. In addition to the operation of the existing air burner with a mixture of oxygen and re-circulated flue gas, two oxy-fuel burner concepts will be tested to identify the best strategy for future application of this technology. Detailed measurements of steam quality, heat flux and temperatures will be used to show the differences to the air fired performance of the boiler. Start-up and operational procedures will focus on the safe operation and a seamless transition between air and oxy-fuel operation.

Due to the short duration of the demonstration and to keep capital requirements low, the demonstration will not include the construction of a dedicated ASU and CPU. Rather, the oxygen required for combustion will be supplied by trucks in liquid form and evaporated on site for use in the test boiler. The flue gas generated will be vented as a mixture of CO_2 and water to atmosphere.

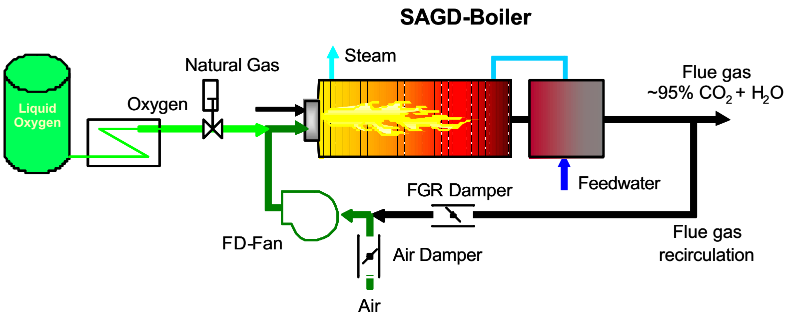

Figure 3: OTSG Oxy-Fuel Combustion Demonstration

Commercial and Economic Aspects of Technology

One of the major objectives of this project is to quantify the capital and operating costs of the technology when implemented on a commercial scale. For this purpose, the target site for the commercial application is Suncor's Firebag in-situ facility, and the target implementation is an installation that would capture the emissions, on a retrofit basis from four 250 MMBtu/hr OTSG installation. The costs were estimated for the capture, purification and compression of the carbon dioxide to pipeline-ready specifications; no costs were included for the transportation and sequestration of the carbon dioxide once captured, as these are likely to vary widely depending on the location of the boilers.

A major economic challenge with the economics of capturing CO_2 from OTSGs and other similar gas-fired combustion sources is that current carbon dioxide capture technologies are not suitable because of the very dilute concentration (6%) of CO_2 in the flue gas. These low concentrations of CO_2 increase the size of the equipment and energy costs of post-combustion capture equipment, and add significantly to their costs. In addition, in-situ operations are situated in remote Northern Alberta, Canada, and labour and material costs are significantly higher than would be experienced in other areas, such as the US Gulf Coast.

Table 1 Comparison of the commercial aspects of CO_2 capture technologies for OTSGs

Post-Combustion with Amines	Oxy-fuel Combustion
90% CO_2 capture rate	99% CO_2 capture rate
Large steam requirements, ~ 3-4 MMBtu/tonne	Requires power for oxygen, blowers and CO_2 Processing
\$190 - \$250/tonne CO_2 avoided	\$120 - \$150/tonne CO_2 avoided
Commercially available	Need to demonstrate oxy-fuel burners and CO_2 purification
Large system footprint	Utilizes less natural gas due to warm flue gas recycle.
	Produces large quantity of usable water

Cost estimates for amine systems were not explicitly prepared for this study. The cost estimates provided were taken from data 2008 data published in the Alberta CCS Development Council Final Report issued March 2009[v]. The costs have been escalated by 5% per year to put them on a consistent time basis with the oxy-fuel costs presented.

Cost estimates for the oxy-fuel case (+/- 30%) were prepared as part of the ongoing Phase I Study. The study basis assumes a set of four 250 MMBtu/hr boilers modified for flue gas recirculation. The air separation plant will produce ~2200 tonnes per day of 97% oxygen at low pressure. The CPU will process ~1400 tonnes per day of 99.5% CO_2 at 14 MPa.

The business model proposed calls for Praxair to design, construct, operate, and maintain the required equipment for the oxy-fuel system (ASU, boiler modifications, CPU). In exchange, the oil field operator will make period payments assumed to be monthly for 15 years. The cost per tonne estimated in Table 1 was calculated by dividing a monthly period payment by the total tonnes of CO_2 produced in the same time period, and then adjusting for parasitic CO_2 generated producing electricity to power the system. The costs can be broken down into a capital recovery factor (~50%), utilities to power the system (~36%), and a labour/maintenance component (~14%). Cost may be lower if more or larger units were installed at the same facility.

6. Project Plan

Phase I of this project which is now underway will optimize the design and costs of retrofitting both a pilot-scale and commercial scale OTSG boiler for CO_2 capture. This Phase is being entirely funded by the Participants, and is anticipated to be completed by mid-2010. Initial activities in Phase I include the establishment of the design basis for a commercial scale boiler as well as a test sized boiler. The "Commercial Boiler" path will optimize the design and costs associated with the integration of the combustion and capture technologies on four full scale OTSG boilers. The "Test Boiler" path will develop demonstration plans and budget costs for separate oxy-fuel combustion tests (Phase II) and a pre-commercial CO_2 capture demonstration (Phase III) on a small OTSG boiler.

Phase II of the project will involve a demonstration of the oxy-fuel technology on a 50 MMBTU "test" OTSG boiler. This phase will modify an existing OTSG boiler for oxy-fuel operations and will operate the modified boiler for up to one month to demonstrate the technical feasibility of oxy-fuel as a means of producing a more pure CO_2 exhaust stream from OTSG operations. The size of unit is "commercial" but has been superseded in recent years by larger equipment. It is an excellent test platform as the oxygen volume requirements match what can be handled by a trucked in, tank stored oxygen supply. Phase II is anticipated to be completed in 2011.

Phase III will include the purification of the flue gas stream to pipeline and sequestration ready CO_2 specifications. This will require the addition of a cryogenic separation facility, in addition to the oxy-fuel OTSG boiler from Phase II. Phase III is anticipated to be completed in 2012-13.

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[i] 2009-2025 Canadian Crude Oil Forecast, 2009; Canadian Association of Petroleum Producers (http://www.capp.ca/aboutUs/mediaCentre/NewsReleases/Pages/2009-2025CanadianCrudeOilForecastandMarketOutlook.aspx#zPGkXCRBIO2p)

[ii] 2009 Suncor Report on Sustainability (www.suncor.com/sustainability)

[iii] Energy & Fuels 2003, 17, 1034-1039: Degradation Pathways for Monoethanolamine in a CO2 capture Facility: Brian R. Strazisar, et. al, NETL 2003

[iv] Statoil 2009: CO_2 Masterplan Mongstad (http://www.statoil.com/no/NewsAndMedia/News/2009/Downloads/Masterplan%20Mongstad%20English%20Summary.pdf)

[v] Alberta Carbon Capture and Storage Development Council 2009: Accelerating Carbon Capture and Storage Implementation in Alberta (http://www.energy.alberta.ca/Org/pdfs/CCS_Implementation.pdf)